Journal of Urban Health: Bulletin of the New York Academy of Medicine Vol. 78, No. 3, September 2001

The Risk Environment for HIV Transmission: Results from the Atlanta and Flagstaff Network Studies

Richard Rothenberg, Julie Baldwin, Robert Trotter, and Stephen Muth

ABSTRACT *The purpose of this study was to investigate the hypothesis that human immunodeficiency virus (HIV) transmission may be facilitated or obstructed by network structure, incorporating a measure of risk that combines true risk and surrogates. Persons at presumed high risk for HIV were enrolled in long-term follow-up studies of urban and rural networks in Atlanta, Georgia, and Flagstaff, Arizona. We focused on respondents who were also contacts to evaluate information on both sides of the observed dyads and constructed a Risk Indicator, based on a four-digit binary number, that permitted assessment and visualization of the overall risk environment. We constructed graphs that provided visualization of the level of risk, the types of relationships, and the actual network. Although some of the findings conform to the hypotheses relating network structure to transmission, there were several anomalies. In Atlanta, HIV prevalence was most strongly related to men with a male sexual orientation, despite the widespread use of injectable drugs. In Flagstaff, an area of very low prevalence and no transmission, the risk environment appeared more intense, and the frequency of microstructures was as great or greater than representative areas in Atlanta. The network hypothesis is not yet sufficiently developed to account for empirical observations that demonstrate the presence of intense, interactive networks in the absence of transmission of HIV.*

KEYWORDS *HIV, Risks, Social networks, Transmission dynamics.*

INTRODUCTION

The goal of many epidemiologic studies is to determine the risk, for some outcome of interest, of people with a given characteristic compared to people without that characteristic. That simple concept has been the underlying theme for 50 years of complex and dynamic methodologic development. The foment continues on many fronts: fundamental statistical approaches in observational data,[1–3] the quality and consistency of data acquisition and adherence to scientific principles,[4,5] and the limits of interpretability of epidemiologic findings.[6] Less prominent in this self-examination, however, is the notion that the concept of relative risk may be of limited value in understanding some epidemiologic phenomena. The dynamics of transmis-

Dr. Rothenberg is with the Department of Family and Preventive Medicine, Emory University School of Medicine, Atlanta, Georgia. Drs. Baldwin and Trotter are from Northern Arizona University, Flagstaff. Mr. Muth is a consultant with Quintus-ential Solutions, Colorado Springs, Colorado.

Correspondence and reprints: Richard Rothenberg, MD, Professor, Department of Family and Preventive Medicine, Emory University School of Medicine, 69 Butler Street SE, Atlanta, GA 30303. (E-mail: rrothen@emory.edu)

sion of human immunodeficiency virus (HIV) and sexually transmitted diseases (STDs), for example, require an understanding of how persons with varying risk characteristics interact with each other. The classic measures of association—relative risk and attributable risk—do not describe how people associate. Nonetheless, a number of mathematical modeling approaches are based on initial classification of persons into categories (or compartments) based on risk, with assessment of the interaction of such groups.[7]

Although of considerable heuristic value, such models often serve more to confirm intuitive notions of transmission than to provide a comprehensive theoretical framework[8] and may leave unanswered certain fundamental questions about disease transmission. An alternative approach, but one that raises many of the same fundamental issues, is the use of social network analysis to define transmission dynamics. Although only recently applied to the field of infectious disease transmission,[9] the burgeoning interest in this approach has led to considerable efforts in data collection and analysis. A number of empirical studies have provided a sense of the general linkage between network configuration and HIV/STD prevalence and transmission,[10–16] but a comprehensive hypothesis on the specific linkage of behavior, networks, and transmission has not yet emerged.

In the current study, we propose an analytic framework for assessing the risk environment in locations of purported risk for HIV or STD transmission and demonstrate the complexities of risk interaction that inhibit our understanding, both empirical and theoretical, of the relationship of risk and network structure to transmission.

METHODS

Data Sources

The data for this study derive from a 4-year longitudinal assessment of the epidemiologic, behavioral, and network characteristics of persons in the inner city of Atlanta, Georgia; the methods have been described previously.[15] Briefly, we enrolled 228 persons in six community chains of persons who were at presumed high risk for HIV transmission either because of their drug use or sexual activity. These six community chains were begun with two index individuals in each of three distinct geographic areas in Atlanta. We attempted up to five interviews, spaced 6 months apart, that included a comprehensive evaluation of their epidemiologic and demographic characteristics, past medical history, current and past sexual activity, current and past drug use and needle-sharing, and current personal networks of sex, drug, needle-sharing, and social partners. The initial design required the formation of six connected components (groups within which there is a path of some length from every person to every other person) and permitted a substantial number of participants to appear as both respondents and contacts, thereby providing information on both sides of a dyad. Although there were some interconnections, the six chains remained largely separate through the course of the study.

We also used data from a similar study conducted in Flagstaff, Arizona, a semirural community with an appreciable level of risk taking, but very low prevalence of HIV. Although virtually identical instruments were used in this study, the designs differed because it was not possible to maintain chains in distinct geographic areas. In addition, the Flagstaff Rural Network Study focused more closely on couples who shared needles and had sexual relations, eliciting fewer social or noninjection drug contacts. In some instances, these couples were part of several distinct chains;

the components of these chains thus overlapped, but were kept separate for analysis purposes. The Flagstaff study did not elicit information on needle-sharing behavior through multiple historical questions from many participants, but relied on the presence or absence of a current needle-sharing partner to determine such behavior.

Tools for Analysis

We examined, using standard definitions, not only the individual risk factors that are usually obtained in a risk analysis, but also created special groups for the purposes of developing an overall Risk Indicator. For example, the overall epidemiologic category of MSM (men who have sex with men) included men who expressed a sexual orientation toward other men or who, in other lines of questioning, acknowledged sexual contact of any type with other men. There were 45 persons in this category in Atlanta. On the other hand, for purposes of a Risk Indicator, we included only men who acknowledged a male sexual orientation (n = 15 in Atlanta) in one of the groups. The purpose for this distinction, as discussed below, was to distinguish between behavioral categories and behavioral acts.

To construct a measure of overall risk, we made a distinction between acts that involved a high potential for actual transmission of organisms and acts that were surrogates for such risk (MSM, in that sense, is a surrogate for unprotected anal intercourse; IDU (injecting drug user) is a surrogate for needle-sharing). We ordered these in accordance with common perceptions of the level of risk incurred by particular behavioral acts, which generally deem needle-sharing to be the most risky activity (that is, it confers the greatest probability of transmission from a single act), followed by receptive, then insertive, anal intercourse.[17–19] From this order, we constructed a four-digit binary number (0000 to 1111): The most significant digit (the 2^3 place) was a 1 if markers with direct potential for transmission (sharing needles and unprotected anal intercourse, either receptive or insertive, with men or women) were present and was otherwise 0; the next significant digit (the 2^2 place) contained information on whether the respondent was an IDU or had experienced unprotected vaginal/oral intercourse; the next lower digit (the 2^1 place) indicated if the respondent was a man who had sex with other men; the least significant digit (the 2^0 place) was 1 if other surrogates were present (women who have sex with women [WSW], sex with an IDU, exchange of drugs or money for sex). The final score for a person included all the designations for which the person was eligible. The final number, difficult to interpret in binary format, was translated back to its decimal format and ranged from 0 to 15. This number provided a clear distinction between a person whose risk designation was equal to or greater than 8, indicating risks of major consequence, and a person whose risk designation was less than 8, indicating lesser risks and risk surrogates. Because of the uncertainty associated with the risks of transmission, their relative ordering is more an ordinal than interval measure and is meant to serve as a heuristic for demonstration of the risk environment.

This risk designation was melded with unique identifiers to construct graphs of network interaction using UCInet-5[20] and Krackplot.[21] The unique identifier was subsequently removed, providing a picture with node names that convey a direct sense of the riskiness of the environment in the setting of an actual network. We assessed the sensitivity of this tool to incorrect information by comparing respondents' answers to questions that should be internally consistent (for example, a history in the past 6 months of sharing needles and current needle-sharing partners) and externally consistent (verification of relationships by independent interview of persons on both sides of dyad).

Analytic and Visual Approaches

We examined the association of individual risk factors and of the components of the Risk Indicator with the presence or absence of prevalent HIV in Atlanta (there was only one HIV-positive person in Flagstaff). The three people with seroconversions in Atlanta did not provide sufficient end points to use incidence as a dependent variable. We used the Risk Indicator and its component variables and standard sociodemographic markers to construct a set of logistic regressions for the effect of these factors on the presence of HIV infection. The distribution of the Risk Indicator in the total population of responders and in the subset of persons who were both respondents and contacts was examined. Using 8 as the cutoff for the Risk Indicator, the joint distribution of the Risk Indicator among respondents and contacts was determined to assess the extent of assortative mixing. Representative examples of graphs of the social networks of the community sites (Atlanta) and the community chains (Flagstaff) were chosen to display the types of connections and the level of risk of the participants.

RESULTS

Population Characteristics

In Atlanta, there were 292 respondents, 228 who were part of the community chains and 64 "isolates" (persons interviewed because of their social proximity to these chains, but who were not named as contacts). Of these 292, there were 213 respondents (73%) who also appeared as contacts. Of the 95 respondents who appeared in community chains in Flagstaff, 86 (91%) were also named as contacts. At both sites, the subset of respondents who were also contacts (data not shown) varied in only minor ways from the total group, but the total groups differed substantially at the two sites (Table 1).

The Atlanta group was somewhat older, predominantly African American, and with a somewhat smaller proportion of men. There was a higher proportion of MSM and WSW in Atlanta, but a smaller proportion of both men and women who admitted to unprotected anal, vaginal, or oral sex in Atlanta compared to Flagstaff. Atlantans more frequently acknowledged injecting drug use, but this may be attributed to the small percentage of persons in Flagstaff who responded to the multiple questions used to elicit such activity. The needle-sharing behavior of Flagstaff participants, as determined by the presence of a current needle-sharing partner, was much higher (76%) than that in Atlanta (23%). Both groups acknowledged frequent sex with an IDU (although again, this type of historical question underestimated the frequency in Flagstaff, as judged by current relationships). The proportion of persons who exchanged money or drugs for sex was considerably higher in Atlanta.

Risk Indicator

The population studied in Flagstaff had a more risky overall environment (mean Risk Indicator 10.2) than the population in Atlanta (6.8) (Table 1). Of persons in Flagstaff, 79% had a Risk Indicator greater than or equal to 8, compared with 47% in Atlanta (Table 2). The distribution of Risk Indicators at the two sites also suggested greater aggregation, or assortative mixing, in Flagstaff than in Atlanta. For 66% of dyads in Flagstaff, both members had Risk Indicators greater than or equal to 8, suggesting a considerable aggregation of higher-risk people with each

TABLE 1. Contrasting sociodemographic and risk characteristics of the respondent populations in Atlanta, Georgia (Urban Network Study), and Flagstaff, Arizona (Rural Network Study)

	Atlanta, %	Flagstaff, %
Over 30 years old	91	75
Male	55	66
African American	90	50
Men who have sex with men	17	12
Women who have sex with women	45	33
Insertive anal sex (with men or women)	23	22
Unprotected anal sex (with men or women)*	56	78
Unprotected vaginal or oral sex	59	84
Injecting drug users (IDU, self-acknowledged)†	26	20
Share injection equipment	23	76
Sex with injecting drug user	49	37
Received money for sex	53	14
Received drugs for sex	45	12
Gave money for sex	40	4
Gave drugs for sex	49	7
Elements of the Risk Indicator‡		
2^0: WSW, sex with IDU, exchange drugs/money for sex	91	58
2^1: MSM	5	0
2^2: Injecting drug use and/or unprotected vaginal/oral sex	68	84
2^3: Needle-sharing and/or unprotected anal sex	36	79
Risk Indicator levels‡		
Mean	6.8	10.2
Median	5.0	12.0
Mode	5	13

IDU, injecting drug user; MSM, men who have sex with men; WSW, women who have sex with women.

*Among those acknowledging this activity.

†In Flagstaff, few persons responded positively to general questions about needle-sharing, but identified numerous current partners with whom needles were shared. In Atlanta, there was considerably better concurrence in these measures (see text).

‡Calculated as $(0,1)*2^0 + (0,1)*2^1 + (0,1)*2^2 + (0,1)*2^3$. Each 2^i represents a digit in a four-digit binary number, the decimal sum of which is then used as the Risk Indicator. (0,1) means that the associated risks either are or are not present.

other, compared to 25% in Atlanta (Table 2). The degree of assortativeness, as measured by “Q” (the extent to which observations aggregate along the diagonal of an $n \times n$ matrix),[22,23] was nearly identical for the two groups (Atlanta 0.25; Flagstaff 0.27). Since the measure captures only the tendency toward the diagonal and is not sensitive to distributions along the diagonal, Q does not reflect the significant aggregation of high-risk dyads in the Flagstaff data (McNemar $\chi^2 = 43.3$, $P \ll .01$).

Risks and HIV Status

Based on individual risk factors, the strongest relationship to prevalent HIV infection in Atlanta occurred among the 45 MSM (Table 3). Those men who professed a sexual orientation toward other men or who acknowledged sexual activity with

TABLE 2. Comparison of Risk Indicators of respondent-contact dyads for Atlanta, Georgia (N = 778 dyads) and Flagstaff, Arizona (N = 311 dyads), 1995–1999: percentage of respondent-contact pairs in each of the four quadrants of the Risk Indicator

	Risk Indicator*, %			
	Atlanta Respondents		Flagstaff Respondents	
	Lower (<8), %	Upper (≥8), %	Lower (<8), %	Upper (≥8), %
Contacts				
Lower (<8)	38	22	9	13
Upper (≥8)	15	25	12	66

*The cutoff of 8, corresponding to a true risk rather than a surrogate risk, divides each group into four quadrants in accordance with the classification of both the respondent and the contact in each dyad.

TABLE 3. Prevalence of HIV infection in 258 persons with and without given behavioral characteristics tested in the Atlanta Urban Network Study

Behavioral characteristic	Number with behavior	HIV prevalence, % Behavior present	Behavior* absent
Men who have sex with men	45	20	12
Insertive anal intercourse (with men or women)	60	13	14
Receptive anal intercourse (men or women)	27	15	13
Receptive anal intercourse (men only)	8	50	12
Injection drug use	64	13	14
Share injection equipment	57	12	14
Sex with an injecting drug user	121	16	12
Women who have sex with women	115	12	15
Received drugs for sex	117	14	13
Received money for sex	136	15	12
Given money for sex	101	16	10
Given drugs for sex	128	15	13

	IDU (sharing) Yes	No
Men who have sex with men		
Yes	1/3	5/12
	33%	42%
No	6/54	23/189
	11%	12%

*The proportion HIV+ in the remainder of the group, that is, the persons without the given characteristic.

other men had an HIV prevalence of 20% compared with others (12%). Within the smaller group of MSM who acknowledged receptive anal intercourse (n = 8), the prevalence of HIV positivity was 50%. There was no difference with regard to HIV prevalence between MSM who injected drugs and those who did not or MSM who shared injection equipment and those who did not (Table 3, bottom section). Thus, it would appear that the strongest risk for being HIV positive resided within the subgroup of MSM and, within that group, among men who experienced receptive anal intercourse.

The importance of homosexual activity in a risk environment dominated by drug use was further demonstrated in two logistic regressions that examined the effect of risk, controlling for age, sex, and ethnicity, on HIV positivity (Table 4). The overall Risk Indicator was not associated with HIV prevalence (odds ratio [OR] = 1.1, 95% confidence interval [CI] 0.5–2.3). Numerous other models confirmed that injection drug use and needle-sharing did not have a significant relationship to HIV positivity (data not shown). The elements of the Risk Indicator (see Table 1) were also unassociated with HIV status, except for the factor included in the 2^1 digit of the four-digit binary number, that is, the factor associated with a man declaring he had a male sex orientation (OR = 5.1, 95% CI 1.5–17.5). There were no interactions of this term with the component that described injection drug use and needle-sharing (the 2^3 digit) or with other measures that could be substituted for either of these terms (data not shown).

Internal and External Concordance

In Atlanta, 75% of respondents gave concordant answers to general questions about their needle-sharing practices in the past 6 months and their specific practices

TABLE 4. Results of logistic regression to assess the association of the Risk Indicator and its components on HIV-positivity in the Atlanta Urban Network Study

	Referrent category	Odds ratio	95% Confidence intervals
Risk Indicator alone			
Risk Indicator	<8	1.1	0.5–2.3
Age	<30	0.9	0.3–3.3
Sex	Male	0.9	0.4–1.9
Ethnicity	Other than African American	2.2	0.4–10.4
Components of Risk Indicator			
2^0: WSW, sex with IDU, exchange drugs/money for sex		1.1	0.3–4.1
2^1: MSM	Behavior absent	5.1	1.5–17.5
2^2: Injecting drug use and/or unprotected vaginal/oral sex		0.6	0.3–1.3
2^3: Needle-sharing and/or unprotected anal sex		1.0	0.4–2.4
Age	<30	1.1	0.3–4.5
Sex	Male	1.1	0.5–2.5
Ethnicity	Other than African American	1.8	0.3–8.6

IDU, injecting drug user; MSM, men who have sex with men; WSW, women who have sex with women.

with current partners. There were 3% who stated that they had shared needles in the past 6 months, but did not do so with current partners. Most important, 22% denied needle-sharing in the past 6 months, but acknowledged doing so with current partners. Similar estimates could not be calculated for Flagstaff because, as noted, 6-month drug use history was obtained from only a small proportion of the respondents. In Atlanta, both sides of the dyad confirmed the presence or absence of sexual relationship in 84% of responses, and confirmed a needle-sharing relationship in 78%. In Flagstaff, respondent and contact were concordant 88% of the time with regard to a sexual relationship and 59% of the time with regard to a needle-sharing relationship.

Risk Configuration

Visualization of a representative network in Flagstaff demonstrates the marked assortative mixing noted in the data (Fig. 1) and shows that the network is dominated by persons with a high Risk Indicator. Most of the relationships depicted in this figure are both sexual and needle-sharing, and this connected component shows considerable group structure, with large, interacting cycles of drug and sex activity. The larger chains in Flagstaff confirm these findings, but the large number of nodes precludes their clear visualization with this technique.

A network in Atlanta in which transmission of HIV actually took place (Fig. 2)

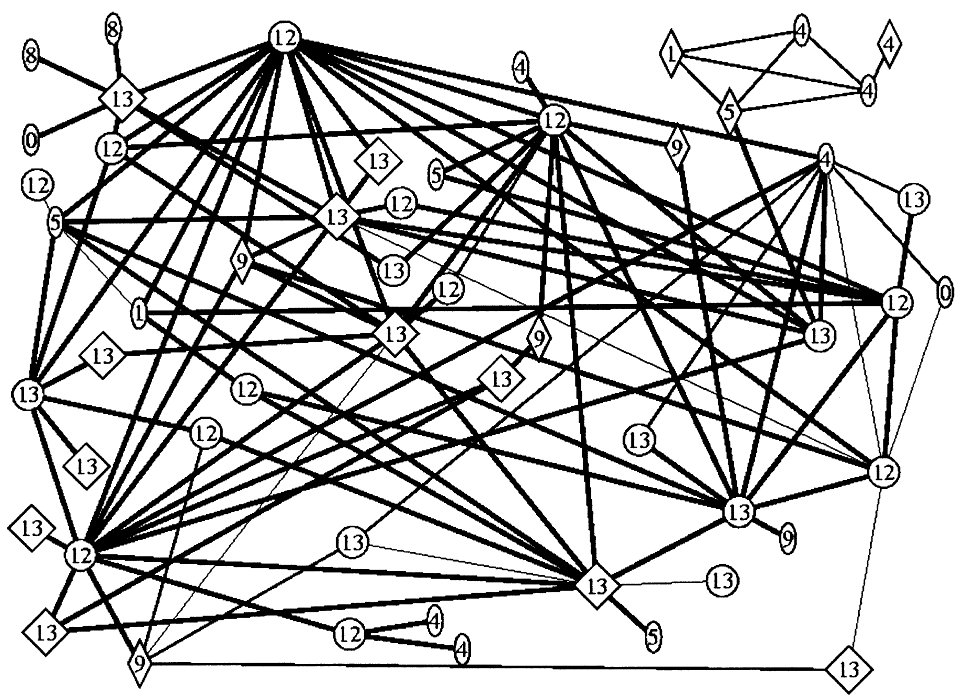

FIGURE 1. Interaction of persons* in a community chain in Flagstaff, Arizona, 1995–1998. *Numbers are Risk Indicators (see text). Shapes reflect gender: Circles or ovoids are men, and diamonds are women. The thickness of the line represents the kind of contact: The thickest lines represent simultaneous sexual and needle-sharing connections; intermediate lines convey either sex or needle sharing; thin lines reflect neither sex nor needle connections.

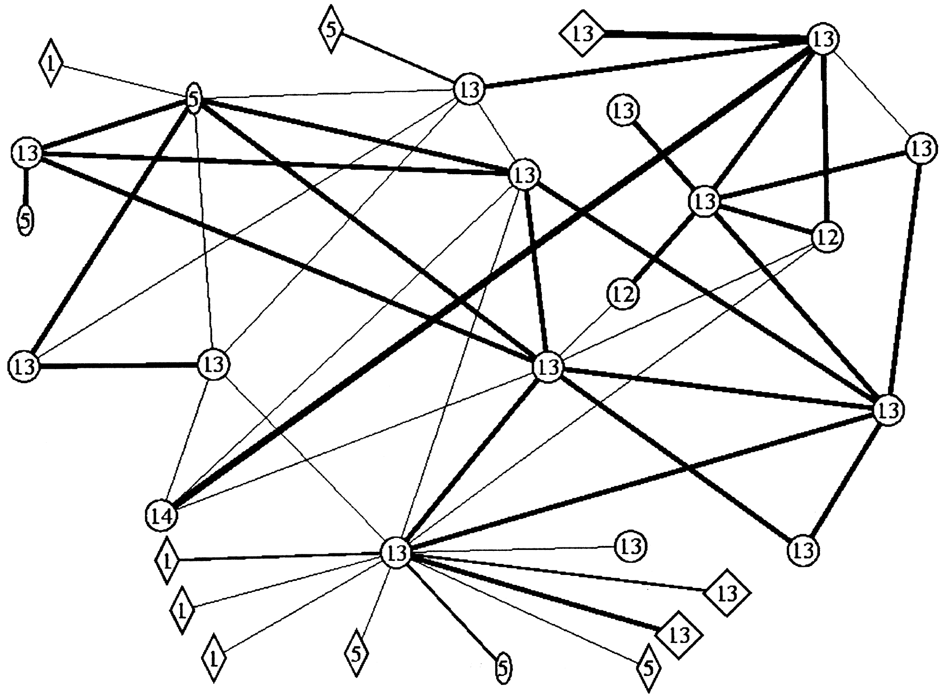

FIGURE 2. Network configuration* for a community group in Atlanta, Georgia, 1995–1999, in which HIV transmission took place. *Numbers are Risk Indicators (see text). Shapes reflect gender: Circles or ovoids are men, and diamonds are women. The thickness of the line represents the kind of contact: The thickest lines represent simultaneous sexual and needle-sharing connections; intermediate lines convey either sex or needle sharing; thin lines reflect neither sex nor needle connections.

was similar to the one displayed for Flagstaff (Fig. 1) in its general properties, although there were fewer participants. The Atlanta group has evidence for substantial assortative and disassortative mixing (that is, the Risk Indicator is not uniformly high), as well as complex interacting microstructures. In contrast, a representative network from a community group in which HIV transmission was not known to have taken place (Fig. 3) reveals a lesser aggregation of persons at high risk and fewer microstructures—more a dendritic pattern with occasional closed triads. All three figures provide an immediate grasp of the risk environment through the simultaneous depiction of Risk Indicators, the types of network connections, and the actual network structure.

DISCUSSION

One emerging concept for the role of social networks in the transmission of sexual and blood-borne pathogens is facilitation through the presence of microstructures or cycles. Such groupings, the simplest of which is the concurrency of sexual partnerships,[24,25] provide an opportunity for dissemination of organisms within small, closely linked subsets of people who not only have ties with each other, but also have ties to other persons and groups.[12–15] In contrast, the pattern of dendritic spread (connected nodes with contacts that do not appear to interact and do not

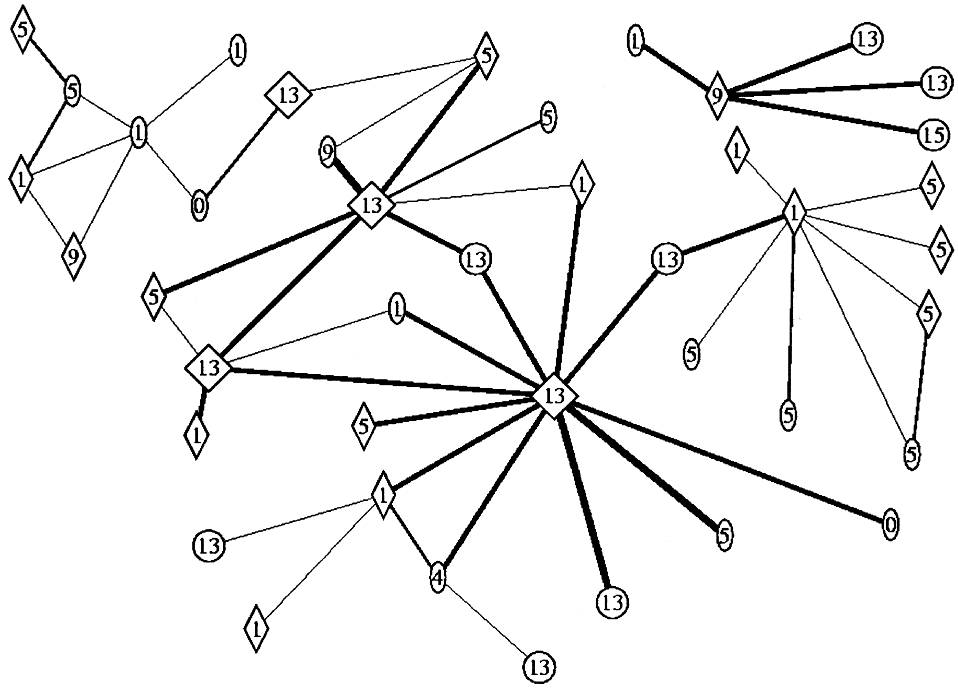

FIGURE 3. Network configuration* for a community group in Atlanta, Georgia, 1995–1999, in which HIV transmission was not known to have taken place. *Numbers are Risk Indicators (see text). Shapes reflect gender: Circles or ovoids are men, and diamonds are women. The thickness of the line represents the kind of contact: The thickest lines represent simultaneous sexual and needle-sharing connections; intermediate lines convey either sex or needle sharing; thin lines reflect neither sex nor needle connections.

form such structures) is postulated to be associated with low-level endemic transmission.[16] Such notions are confirmed by work with modeling of STD epidemics, in which increasing structure is viewed as increasing opportunities for concurrency.[26]

When the characteristics of persons within networks are also taken into account, notions of assortative and disassortative mixing may have considerable explanatory power in determining the rate and size of epidemic spread.[22,27,28] Assortative mixing may be associated with potential rapid transmission within high-risk groups, but with less spread in the general population. Disassortative mixing would provide the opposite picture: slow, but sustained, transmission through the general population. Since most populations are heterogeneous with regard to mixing pattern, it is likely that some optimal combination of assortative and disassortative mixing, embedded in a network with numerous microstructures, would be associated with rapid, generalized spread. (Perhaps such a situation is associated with the now-popular concept of a "tipping point" in disease transmission.[29])

Several anomalous results in the data presented here challenge the relationship of network structure and behavioral characteristics to transmission. The population in Atlanta, though involved in drug use, needle-sharing, and sexual activity, demonstrates little association between behaviors thought to incur the highest risk and prevalent infection with HIV. We structured the Risk Indicator to place the behaviors most associated with transmission (sharing of needles, acknowledgement of insertive anal intercourse, receptive anal intercourse by men or women, or failure to use condoms with anal intercourse) in the dominant risk category (the 2^3 place). The remaining components were arranged in diminishing order of surrogate risk (self-acknowledged injection drug use; self-acknowledged male-male orientation; other markers, such as sex with an IDU or exchange of drugs or money for sex).

For each person in the sample, the risk is a transformed total of all the groups into which he or she may fall. The default assumption inherent in a binary approach is that each element of the Risk Indicator differs from the preceding element by a factor of 2 (in a decimal combination, the factor would be 10); for example, those with acknowledged needle-sharing have twice the risk of those who report that they inject drugs in this construct (the latter, a surrogate marker, includes the former, a direct risk, as a subgroup and hence has its influence diluted). Although the actual relationship is not known with certainty, the binary system approximates known information and is a conservative approach.

In these data, the overall Risk Indicator was not associated with HIV prevalence, and all of the risk for HIV positivity resided in the component (the 2^1 place) that included men who acknowledged their sexual orientation toward other men ($n = 15$). Of these men, 60% (9/15) were HIV positive. Although many of these were also classified in the highest-risk category (the 2^3 place), they constituted only 12% of that group, and their effect was largely diluted. Thus, a small group with high prevalence of HIV, but accounting for only 25% of HIV infection in the overall group, dominated the epidemiologic analysis. Although internal and external concordance was imperfect in Atlanta, the level of disagreement was probably not high enough to have altered these findings significantly.

It would be difficult to justify a reordering of our sense of the probabilities of transmission based on these data. Rather, they point to an incomplete view of a complex picture and, in light of a prevalence in this group of 13.3% overall and an incidence of 1.8% per year, to the fact that a purely epidemiologic analysis fails to capture the interaction of multiple risks.[15] The epidemiologic data substantiate the importance of male-male sexual activity in an environment dominated by drug use, a finding confirmed by a recent preliminary report,[30] but do not provide illumination of the transmission dynamics. Although we were not able to perform the same type of epidemiologic analysis using seroconversion as an outcome (since there were only three end points), it is noteworthy that male-male sexual activity was not involved in any of these seroconversions.

Visualization of a group in which seroconversion did take place (Fig. 2) is more suggestive of the general environment that supports transmission. The presence of multiple pathways between persons, incorporating multiple risks and with immediate visualization of the gender of participants and the nature of their interaction, supplies a more comprehensive picture of the transmission setting. In contrast, a typical network in which transmission did not take place showed a more dendritic pattern, albeit with a number of cycles, and less-intense interaction. These pictures are supported by actual quantitative counts of microstructure and other network properties that have been previously reported.[15]

Although a purely epidemiologic approach does not provide a more comprehensive picture of transmission, our network understanding of transmission is also incomplete. High levels of risk and marked structural interaction (numerous cycles) dominate the social network configuration in Flagstaff (Fig. 1), an area of very low prevalence where no transmission was detected. These observations appear to contravene the posited relationship of network structure to transmission. A simple explanation is that "sufficient" introduction of the virus has not occurred (although there was at least one known person who was HIV positive in this community), and that this community is an HIV epidemic waiting to happen. Since the close of data collection, nearly 3 years ago, such an epidemic has not occurred (R. Trotter and J. Baldwin, oral communication, May 2001).

How this type of risk environment, and its counterpart in Atlanta (Fig. 2), can be structurally similar, yet experience markedly different prevalences, is not immediately apparent. The frequency of viral introduction may provide some explanation, as may the age of the participants, the age of the network, and the age of the epidemic in the community. Clearly, we must pursue in greater depth why persons with similar behaviors in similar or differing network settings incur different risks (for example, the wide variation in HIV prevalence among groups of IDUs[31]) and the determinants of rapid increase[32] or decrease[33] in disease incidence in settings in which high-risk behavior is frequent.

Our current hypotheses remain incomplete and speak to a need to incorporate other macro- and microlevel societal issues. For example, Laumann and colleagues[34] suggested that ethnic separation patterns play an important role by providing a network mechanism for the concentration of prevalence among African Americans. Their hypothesis—assortative mixing with regard to ethnicity, but disassortative mixing with regard to level of risk—was demonstrated empirically in a follow-up study.[35]

The empirical approach that underlies this discussion suffers from several well-recognized methodologic problems, such as the adequacy of self-reported risk and the potential for missing links. Nonetheless, the Risk Indicator we present here in conjunction with network visualization is a nascent attempt to provide a tool for environmental risk assessment. Graphs that simultaneously present the manner in which persons are associated (the network), the quality of those associations (the types of connections), and the risks of the persons involved (a summary number) provide such immediate assessment. This formulation, or further refinements, may furnish both qualitative and quantitative links between networks and disease transmission and may be of use in orienting the acquisition of empirical information and the development of modeling constructs.

REFERENCES

1. Goodman SN. *P* values, hypothesis tests, and likelihood: implications for epidemiology of a neglected historical debate. *Am J Epidemiol.* 1993;137:485–496.
2. Greenland S. Randomization, statistics, and causal inference. *Epidemiology.* 1990;1: 421–429.
3. Feinstein AR. *P*-values and confidence intervals: two sides of the same unsatisfactory coin. *J Clin Epidemiol.* 1998;51(4):355–360.
4. Feinstein AR. Scientific standards in epidemiologic studies of the menace of daily life. *Science.* 1988;242:1257–1263.
5. Savitz DZ, Greenland S, Stolley PD, Kelsey JL. Scientific standards of criticism: a reaction to "Scientific standards in epidemiologic studies of the menace of daily life," by A. R. Feinstein. *Epidemiology.* 1990;1:78–83.
6. Taubes G. Epidemiology faces its limits. *Science.* 1995;269:164–169.
7. Garnett GP, Anderson RM. Factors controlling the spread of HIV in heterosexual communities in developing countries: patterns of mixing between different age and sexual activity classes. *Phil Trans R Soc Lond B.* 1993;342:137–159.

8. Rothenberg RB. Model trains of thought. *Sex Transm Dis.* 1998;24:201–203.
9. Klovdahl AS. Social networks and the spread of infectious diseases: the AIDS example. *Soc Sci Med.* 1985;21(11):1203–1216.
10. Friedman SR, Neaigus A, Jose B, et al. Sociometric risk networks and risk for HIV infection. *Am J Public Health.* 1997;87:1289–1296.
11. Potterat JJ, Rothenberg RB, Muth SQ. Network structural dynamics and infectious disease propagation. *Int J STD AIDS.* 1999;10:182–185.
12. Potterat JJ, Phillips-Plummer L, Muth SQ, et al. Risk network structure in the early epidemic phase of HIV transmission in Colorado Springs. *Sex Transm Infect.* In press.
13. Potterat JJ, Muth SQ, Rothenberg RB, et al. Sexual network structure as indicator of epidemic phase. *Sex Transm Infect.* In press.
14. Rothenberg RB, Potterat JJ, Woodhouse DE, Muth SQ, Darrow WW, Klovdahl AS. Social network dynamics and HIV transmission. *AIDS.* 1998;12:1529–1536.
15. Rothenberg RB, Long D, Sterk C, et al. The Atlanta urban networks study: a blueprint for endemic transmission. *AIDS.* 2001;14:2191–2200.
16. Wylie JL, Jolly A. Patterns of chlamydia and gonorrhea infection in sexual networks in Manitoba, Canada. *Sex Transm Dis.* 2001;28(1):14–24.
17. Mastro TD, de Vincenzi I. Probabilities of sexual HIV-1 transmission. *AIDS.* 1996;10(suppl A):S75–S82.
18. Royce RA, Sena A, Cates W, Cohen MS. Sexual transmission of HIV. *N Engl J Med.* 1997;336(15):1072–1078.
19. Vittinghoff E, Bucbinder SP, Judson F, Douglas JMD, MacQueen K. Per contact risk for transmission of HIV associated with four types of homosexual contact. Paper presented at: Fifth Conference on Retrovirus and Opportunistic Infections; February 1–5, 1998; Chicago, IL.
20. Borgatti SP, Everett M, Freeman L. *Ucinet V for Windows: Software for Social Network Analysis*. Natick, MA: Analytic Technologies; 1999.
21. Krackhardt D, Blythe J, McGrath C. *Krackplot. Version 3.0.* Pittsburgh, Pa: Analytic Technologies; 1995.
22. Garnett GP, Hughes JP, Anderson RM, et al. Sexual mixing patterns of patients attending sexually transmitted diseases clinics. *Sex Transm Dis.* 1996;23(3):248–257.
23. Gupta S, Anderson RM, May RM. Networks of sexual contacts: implications for the pattern of spread of HIV. *AIDS.* 1989;3:807–817.
24. Kretzschmar M, Morris M. Measures of concurrency in networks and the spread of infectious disease. *Math Biosci.* 1996;133:165–195.
25. Morris M, Kretzschmar M. Concurrent partnerships and the spread of HIV. *AIDS.* 1997;11:641–648.
26. Kretzschmar M. Sexual network structure and sexually transmitted disease prevention: a modeling perspective. *Sex Transm Dis.* 2000;27(10):627–635.
27. Anderson RM, Garnett GP. Mathematical models of the transmission and control of sexually transmitted diseases. *Sex Transm Dis.* 2001;27(10):636–643.
28. Service SK, Blower SM. HIV transmission in sexual networks: an empirical analysis. *Proc R Soc London B.* 1995;260:237–244.
29. Gladwell M. *The Tipping Point: How Little Things Can Make a Big Difference.* New York: Little Brown and Company; 2000.
30. Janssen R. Serostatus approach to fighting the HIV epidemic (SAFE): a new prevention strategy to reduce transmission. Paper presented at: Eighth Conference on Retroviruses and Opportunistic Infection; February 4, 2001; Chicago, IL.
31. DesJarlais DC, Friedman SR. HIV epidemiology and interventions among injecting drug users. *Int J STD AIDS.* 1996;7(suppl 2):57–61.
32. Patrick DM, Strathdee SA, Archibald CP, et al. Determinants of HIV seroconversion in injection drug users during a period of rising prevalence in Vancouver. *Int J STD AIDS.* 1997;8(7):437–445.
33. DesJarlais DC, Marmor M, Friedmann P, et al. HIV incidence among injection drug

users in New York City, 1992–1997: evidence for a declining epidemic. *Am J Public Health*. 2000;90(3):352–359.

34. Laumann EO, Youm Y. Racial/ethnic group differences in the prevalence of sexually transmitted diseases in the United States: a network explanation. *Sex Transm Dis*. 1999; 26:250–261.
35. Rothenberg RB, Trotter RT, Sterk C, Baldwin JA, Pach A, Maxwell C. Heterogeneity in drug-using networks. Paper presented at: 12th World AIDS Conference; June 28–July 3, 1998; Geneva, Switzerland.